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NEW OBSERVATIONS ON THE VARIABILITY OF THE SUN

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Photometric Observations of the Planets.—(*a*) Simultaneous spectro-bolometric observations of the solar constant of radiation in California and Algeria in 1911 and 1912, and in California and Chile in 1918, (*b*) comparisons of the distribution of radiation over the sun's disk with simultaneous measurements of the intensity of total solar radiation, (*c*) comparisons of the temperature of the earth with the radiation of the sun, and (*d*) several other minor evidences, have all indicated a short irregular periodicity in the sun's emission. In other words, the sun appears to be a variable star ranging through about 0.10 stellar magnitude between extremes and often changing 0.03 magnitude within a few days.

If this is so it must follow that the planets are also variable because they reflect solar light. Guthnick and Prager have made accurate photo-electric photometric comparisons of Saturn and Jupiter with available stars. Their published results led them to state a conclusion adverse to the solar variability (*Veröffentlichungen K. Sternwarte Berlin-Babelsberg*, **2**, Heft III, 1918 (126)). I wrote to Dr. Guthnick pointing out that this conclusion was premature, because the number of published photometric observations was not large, and they might have fallen on dates when the sun's emission was nearly the same. No direct solar observations were available on those dates. Dr. Guthnick has kindly reopened his investigation and sent me results for January, February, March, April and May, 1920.

We have available for comparison on almost all these days observations of the sun by Smithsonian observers at Calama, Chile. But it is not obvious that a comparison between the brightness of the planets and that of the sun should involve identical dates. Two hypotheses of solar variation may be made. First, the sun's emission may vary in all directions proportionally and simultaneously. Second, the sun may be surrounded by a ragged absorbing or radiating envelope so that his emission is unequal in different directions. Under this second hypothesis the rotation of the sun would carry with it shafts of unequal radiation, which would encounter the planets successively according to their heliocentric longitudes. This second hypothesis is plausible in view of the dissymmetry of the solar corona. It has the advantage, too, of not requiring rapid changes of the sun's emission, which would be hard to account for in view of the immensity of the sun.

Dr. Guthnick states that Jupiter varied irregularly and widely in surface conditions during the period of observation so that its fluctuations are not available for solar constant comparisons. Various well-known

causes of variation in addition to the supposed solar changes affect the brightness of Saturn. In the observations recently sent to me Dr. Guthnick has corrected for all of these influences except those associated with phase. These produce quite a large effect, so that, for instance, the comparisons between Saturn and α Leonis show gradually progressive differences ranging from 0.61 to 0.90 stellar magnitude. He states that for 1920 observations the influence of phase is approximately eliminated by subtracting from the given magnitude differences the product of the phase angle in degrees by a coefficient, which before opposition is 0.025, but after opposition is 0.039. These correcting coefficients are, however, inapplicable for observations made within less than 1° of opposition. Saturn then becomes considerably brighter than would be expected.

I have reduced the observations on Saturn to constant phase angle by applying the coefficients just mentioned. On three dates, namely, Feb. 25, Feb. 28 and March 1, the phase angle is less than 0.5°, so that the corrections are not applicable for these dates. The observation of March 13 is stated by Dr. Guthnick to be of small weight because of unfavorable sky conditions in Berlin. Those of April 23 and May 12 are not of very great weight because Saturn was too near the horizon.

In a first comparison I employed solar constant observations made in Chile on even dates with the observations made in Berlin. The result was so unsatisfactory as in my judgment to discredit the first hypothesis of a solar variation, appearing simultaneously in all directions. I then turned to the second hypothesis, making allowance for differences of heliocentric longitude of the earth and Saturn, and also for differences of terrestrial longitude and times of observing between Chile and Berlin. I thus arrived at the results given in the following table. In addition to the six days mentioned above as unsuitable, Feb. 7 is also unsatisfactory, owing to very cloudy conditions in Chile.

There remain nine days suitable for comparison. These nine days are on the whole favorable to the view that the sun and Saturn each varied in brightness by two per cent, and that their variations were synchronous and proportional. The largest discrepancy which occurs among these nine comparisons is for March 9.5/10 and it indicates an error of slightly more than 0.5 per cent, or 0.005 magnitude. This amount of error is surely to be expected occasionally. Indeed it is very remarkable how accurate the results appear to be both in Berlin and Chile.

Extraordinary March of Solar Radiation 1919–20.—For about six years the intensity of solar radiation has almost always exceeded the mean value, 1.933 calories per square centimeter per minute, which was found from the Washington, Mt. Wilson and Mt. Whitney observations of 1902–12, as published in Volume III of the Annals of the Astrophysical Observatory. This condition of affairs was expected to attend the return of increased solar activity, otherwise evidenced by numerous sunspots,

DATE	SATURN—α LEONIS	PHASE ANGLE	SATURN ⊙ LONGITUDE	EARTH ⊙ LONGITUDE	Δ	SOLAR LAG. $\frac{25.4\ \Delta}{360}$ DAYS	NEAREST CORRESPONDING DATE, CALAMA	SOLAR CONSTANT	GRADE	CORRECTION FOR PHASE* M.	CORRECTED SATURN—α LEONIS. M.
Jan. 29.6	+0.743	3.18°	157° 13′	128° 55′	28° 18′	2.0	Jan. 27	1.975	S	—0.079	+0.664
Feb. 8.6	0.715	2.16	36	139 3	18 33	1.3	Feb. 7	1.946	U+	0.054	0.661
14.5	0.704	1.53	49	140 59	16 50	1.2	13	1.962	U+	0.038	0.666
16.5	0.701	1.30	53	147 5	10 48	0.8	15	1.951	S—	0.032	0.669
17.5	0.690	1.18	55	148 6	9 49	0.7	17	...	...	...	...
18.6	0.687	1.07	58	149 7	8 51	0.6	18	1.971	S—	0.027	0.660
19.5	0.681	0.96	158 0	150 6	7 54	0.6	19	1.983	S—	0.024	0.657
23.5	0.637	0.53	8	154 7	4 1	0.3	23	...	...	...	...
25.5	0.633	0.34	12	156 7	2 5	0.1	25	1.987	E—, S	0.008	0.625
28.5	0.614	0.25	18	159 8	—0 50	—0.1	28	1.953	S—	0.010	0.604
Mar. 1.5	0.653	0.40	22	161 8	—2 45	—0.2	Mar. 1	1.980	S—	0.016	0.637
9.5	0.711	1.26	40	169 8	—10 28	—0.7	10	1.959	S	0.049	0.662
13.5	0.708	1.70	48	173 6	—14 18	—1.0	14	1.962	VG, S	0.066	0.642
24.4	0.783	2.85	159 11	183 58	—24 8	—1.7	26	1.953	S	0.111	0.672
Apr. 25.5	0.784	2.96	13	185 03	—25 8	—1.8	27	1.966	E, S	0.115	0.669
12.4	0.854	4.54	51	202 41	—42 8	—3.0	Apr. 15	1.944	S—	0.177	0.677
23.4	0.860	5.27	160 14	213 26	—53 2	—3.7	26	1.960	VG+, S	0.205	0.655
May 11.4	0.899	6.04	52	230 52	—70 0	—4.9	May 16	1.957	S	0.235	0.664

* 0.025 and 0.039 phase coefficients before and after opposition.

prominences, faculae. We have now, however, long passed the period of maximum sunspots, so that we should naturally expect the sun's radiation to be falling below the mean value of 1902–12. The results obtained by the Smithsonian observers at Calama, Chile, indicate quite otherwise.

I have computed solar radiation values for each five days interval from July 1, 1919 to March 25, 1920. The mean value is never based on less than two observations, and this minimum occurs only in two instances. All other values depend on three days of observation, more often four, and very often five.

One is immediately struck by the wide fluctuation of the mean values shown. The fluctuation of individual days naturally had a still wider range, reaching in fact to 8%. The mean values cover a range of 5%. With gradually diminishing swings, up and down, the radiation fell from June 1919 to early in October, then suddenly leaped up to a high mean value which it maintained until early in December, and then again suddenly leaped much further and remained from the end of December to the middle of March 1920 at a mean value far in excess of anything which we have any record of, continued for so long a time as three months during the whole fifteen years in which solar constant observations have been carried on with anything like regularity. Towards the end of March an extremely rapid fall of radiation occurred, so that individual values have run as low as 1.86 calories.

1919	A	B	C	D	E	F
June	46	84	37	39	71	53
July	36	54	47	63	57	31
Aug.	53	54	38	36	51	45
Sept.	28	33	30	42	31	30
Oct.	18	57	49	46	59	62
Nov.	60	51	60	43	47	54
Dec.	55	48	54	60	67	81
1920						
Jan.	69	102(?)	74	78	81	70
Feb.		87	60	78	77	68
Mar.	77	65	70	50	10	

In view of this extraordinary march of solar radiation values, it may be recalled that we have been passing through an exceptionally cold and cloudy winter from about the first of December. The cloudiness has prevailed in South America as well as here, so that if it had not been for the introduction of the new method of observing, of which notice was given to the Academy at its last meeting, the observers would not have been able to give us this very continuous record.

At first sight it looks paradoxical that a cold winter could accompany

extraordinarily high values of solar radiation, but it has been not only a cold winter but a cloudy winter. Hence it may have been that the direct effect of the outburst of solar activity was to produce excessive cloudiness which by high reflection diminished the radiation available to warm the earth.

In the preceding table I give the mean values of the solar radiation above mentioned. In each month I have indicated the successive five day periods by the capital letters A, B, C, D, E, and F. The values given are the number of thousandths of a calorie by which the solar radiation of a given time interval exceeds 1.900. Thus, for the first period of June the mean value is 1.946.

March Values.—On or about March 22, great sunspot activity was reported. On March 22 and 23 there were intense magnetic disturbances affecting all observations of terrestrial magnetism and the operation of telegraphs and cables. Remarkable auroral displays followed. In connection with these conditions it is interesting to note the very unusual progress of the solar constant of radiation during the month of March. This is given in the following table

Date	Mean, 11 to 17	18	19	20	21	22	23	24
Value	1.968	1.954	1.940	1.931	1.941	1.927	1.866	1.905

It is highly probable that the results just given will have a special significance in connection with the remarkable outbreak of solar activity to which attention has been drawn.

THE PERMANENT GRAVITATIONAL FIELD IN THE EINSTEIN THEORY

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1. In accordance with the theory of Einstein a permanent gravitational field is defined by a quadratic differential form

$$ds^2 = \sum_{i,k}^{1,..4} g_{ik}dx_i dx_k, \ (g_{ik} = g_{ki}), \tag{1}$$

where the g's, called the potentials of the field, are determined by the condition of satisfying ten partial differential equations of the second order, $G_{ik} = 0$. When the four coördinates x_i are functions of a single parameter, the locus of the point with these coördinates is a curve in four-space. If these functions are of such a character that the integral

$$\int \sqrt{\Sigma g_{ik} dx_i dx_k} \tag{2}$$